Translational R & D Topics

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manufacturing FORESIGHT

A THINK-AND-DO TANK

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Table of Contents

Technology Evaluation Criteria

1. **Economic Impact**: Potential impact of the technology on economic growth and job creation.
2. **Cross-cutting impact:** If matured, the technology would positively impact multiple industry sectors and manufacturers of all sizes in the supply chain.
3. **Identifiable Market Failures**: No single company or industry would invest in technology maturation because the benefits will spillover to competitors or inability to capture benefits.
4. **International benchmarking**: Likelihood of potential first-mover advantage to the U.S.
5. **Private sector investment:** Likelihood that private sector would co-invest with the government.
6. **Leveraging strengths and investments:** Leverages previous investments by the US government in basic research, research infrastructure, raw materials, or supply chains.
7. **US-based Manufacturing**: If matured, the scale-up is likely to be anchored in the U.S.
8. **National Interests**: The technology is aligned with either U.S. national security needs or energy independence goals, or enhancing health outcomes, etc.

TRANSLATIONAL R&D:
POPULATION SPECIFIC MEDICAL DEVICE MANUFACTURING

DESCRIPTION

There is an absence of medical devices to meet the needs of those patients that have a low prevalence conditions (orphan populations), a non-normative anatomy, or are pediatric. Devices for this patient set are often referred to as "population-specific". The current technological, business, and government situation has prevented these devices from being economically viable to develop and manufacture. Devices that are made to serve these populations are often ad-hoc. Targeted advances in low volume manufacturing (including 3D printing), imaging databases, computational codes, and shared facilities will provide the opportunity to realize medical devices for these patients.

Opportunity: The U.S. has both an underserved patient population and a medical device industry that is being threatened by manufacturers abroad, with the opportunity to establish global leadership on manufacturing for low-volume patient populations. A change is required from the current method of providing these patients with needed medical devices. Such a change is possible if all the stakeholders come together in a public private partnership-like collaboration. In a similar fashion to the formation of the Medical Devices Innovation Consortium (MDIC), a private-public partnership could include targeted funding for technology advancement, shared infrastructure to enable enhanced communication and distribution of the costs over many parties, and contributions from health care insurance that will financially benefit from the development of the medical devices.

ECONOMIC IMPACT

The U.S. exports $45B of medical devices per year, growing at compound annual growth rate (CAGR) of 5.8%. [1] [2] The U.S. consumes $133B in medical devices per year [2]. The subset of 3D printed medical devices is expected to reach $2.13B by 2020, with a CAGR of 25.3%. [3] The medical technology sector provides 420,000 jobs. [4]

BROAD INDUSTRY IMPACT

The U.S. is in a unique position to create a broad-based, self-sustaining ecosystem in which the partners will collaborate in the pre-competitive space to design an orphan medical device manufacturing framework. Industry participants gain the advantage of a de-risked the manufacturing and regulatory approval process to streamline development. The potential impact on all patient populations is significant, with large economic benefits to individual companies and society at large.

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[1] IBISWorld, "Medical Device Manufacturing in the US: Market Research Report," Jan 2016.

[2] http://selectusa.commerce.gov/industry-snapshots/medical-device-industry-united-states.html

[3] Markets and Markets, 3D Printing Medical Devices Market - by Component (3D Printers, 3D Bioprinters, Materials, Services & Software), Technology (EBM, LBM, Photopolymerization, 3DP, and DD), Medical Products (Surgical Guides, Equipment, Implant) - Global Forecast to 2020" Sept 2015.

[4] http://advamed.org/res.download/32

If the U.S. does create a public-private partnership, then there is a multifaceted success for all. Once up and running, other countries would find it quite difficult to duplicate the broad support base that created this model.

IDENTIFIABLE MARKET FAILURES - JUSTIFICATION FOR FEDERAL INVESTMENT

The underserved patient populations are a clear indication of the economic infeasibility with the current technology and policy. The cost to develop the underlying technology and databases is high enough that no single company is willing to make the investment.

INTERNATIONAL BENCHMARKING (U.S. ADVANTAGES AND DISADVANTAGES)

The existing U.S. medical device industry (already a worldwide player in medical devices) provides a support system for the devices for the population-specific market. There are more than 6,500 medical device companies in the U.S., mostly small and medium-sized enterprises. The 828 companies in the high tech medical device industry generate in excess of $60 billion in revenue and employ over 88,000 workers.

In terms of disadvantages, the U.S. regulatory climate arguably is a major barrier. In translating technology from the research laboratory to the patient, technologies invented and developed in the U.S. frequently will leave the country for critical early stage clinical trials and approvals before coming back to the U.S. for later application to the FDA and entry into the U.S. market.

PRIVATE SECTOR INVESTMENT

There are numerous large medical device manufacturers, as well as a robust venture capital network to fund medical devices. Further, the medical insurance providers have a financial incentive to progress the development of small-lot medical devices. Combined, these factors create a sustainable private sector investment.

LEVERAGING STRENGTHS AND INVESTMENTS

The U.S. invests in basic and applied research in the medical field, and this technology would help realize clinical applications of this research.

LEVERAGING STRENGTHS AND INVESTMENTS

The U.S. invests in medical device research through the National Science Foundation, National Institute of Health, and the Military.

US-BASED MANUFACTURING

The U.S. ownership of the databases, combined with a strong U.S. medical device manufacturing industry increases the likelihood retaining the manufacturing in the U.S.

NATIONAL INTERESTS

This technology and partnerships will directly benefit the health outcomes of the U.S.

Translational R&D: Continuous Manufacturing of Pharmaceuticals

DESCRIPTION

Major changes in pharmaceutical manufacturing will change this industry dramatically in the next decade. One key change is the development of continuous pharmaceutical manufacturing, which is an end-to-end process that takes raw chemical ingredients and transforms them to finished pills in a non-stop, fully integrated, seamless process. The process can run without interruption, while being carefully controlled in real-time. Changing from batch manufacturing to continuous manufacturing will reinvent pharmaceutical manufacturing in a host of ways: lowering capital costs, shortening processing times, producing a superior product quality, enabling more control over processing parameters, providing flexibility in production quantities, requiring less space, providing better containment, increasing worker safety, and reducing inventory.

In spite of this potential, the technical challenge of the continuous manufacturing process is such that no one company can achieve successful deployment – even large pharmaceutical firms. Beyond the technology cost, the industry must also bear a large regulatory cost when implementing a new process. The technical and regulatory challenges also put continuous manufacturing out-of-reach for the small to mid-sized companies that collectively manufacture more than 60% of U.S. pharma products, and more than 80% worldwide. The technology and the product development pathway needs to be standardized so that producers of all sizes can adopt continuous manufacturing, and also to reduce regulatory risk and facilitate approval.

Opportunity: The government has the opportunity to assist the transition to continuous manufacturing by providing targeted investment in key technology development areas and improved standards and regulations.

ECONOMIC IMPACT

The global market for pharmaceuticals worldwide is approximately $1 trillion, growing at about 5.4% compound annual growth rate (CAGR). Approximately 40% of the market is North America. [1] [2] The U.S. manufactures about $150B of pharmaceuticals per year. [3] [4] The transition to continuous manufacturing would lower healthcare costs in the U.S.

It is estimated that a worldwide conversion to continuous manufacturing of more than 50% of total volume will take place in the next 10 to 20 years. [5] Since the annual sales pharmaceutical sales exceed a trillion dollars worldwide, a quick estimate of the total direct investment required for this technology transformation easily exceeds $100 billion.

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[1] https://www.imshealth.com/files/web/Corporate/News/Top-Line%20Market%20Data/Global%20Prescription%20Sales%20Information5%20World%20figures%20by%20Region%202015-2019.pdf

[2] http://healthcare.globaldata.com/media-center/press-releases/pharmaceuticals/us-pharmaceutical-market-value-will-approach-550-billion-by-2020-says-globaldata

[3] IBISWorld, "Brand Name Pharmaceutical Manufacturing in the US: Market Research Report" Nov 2015

[4] http://www.statista.com/statistics/194301/us-pharmaceutical-preparation-manufacturing-gross-output-since-1998/

[5] "Reinventing Pharmaceutical Manufacturing, Reinventing Pharmaceutical Manufacturing as a National Priority" Fernando J. Muzzio, Director, C-SOPS, an NSF ERC, October 2015

BROAD INDUSTRY IMPACT

The market for pharmaceuticals is very large, and the lowered capital cost of the manufacturing may enable smaller companies to enter the market. The manufacturing technology may also have applications in chemical processing.

IDENTIFIABLE MARKET FAILURES - JUSTIFICATION FOR FEDERAL INVESTMENT

Virtually all health-care related activities in the U.S. involve regulations, and the pharmaceutical industry is not exempt. When considering the transition to continuous manufacturing, companies large and small must account for the full cost of the regulatory burden. The development of new regulations is particularly difficult because regulators cannot, and will not, form partnerships with single companies.

INTERNATIONAL BENCHMARKING (US ADVANTAGES/DISADVANTAGES)

Unfortunately, while continuous pharmaceutical manufacturing technology was conceived in the U.S., and the know-how required to implement it largely resides in the U.S., we are at serious risk of losing the initiative to Europe. The great majority of continuous manufacturing equipment suppliers are based in Europe. Moreover, the European union, through its vision 2020 initiative, and the UK, with several large initiatives, including a National Pilot Plant and It's "Cures" initiative, has made large scale long-term funding available to European academic institutions, and as a result, the level of research activity in Europe is rapidly increasing.

PRIVATE SECTOR INVESTMENT

Large companies have shown their willingness to invest in this area as evidenced by a $65M partnership between Novartis and MIT. [6] Johnson and Johnson has a pilot continuous manufacturing line for its HIV medication. Glaxo-Smith-Kline is building a $29M plant that uses continuous manufacturing. Vertex Pharmaceuticals is building a $30M continuous manufacturing facility for the new cystic fibrosis drug. [7]

LEVERAGING STRENGTHS AND INVESTMENTS

Existing coalitions of industry, academia and government offer an existing structure for coordinated action. Examples include the NSF's Engineering Research Centers or a National Manufacturing Innovation Institute can provide the coalescence point and the central coordination of technology development paired with modified regulations that are adapted to continuous pharmaceutical manufacturing.

US-BASED MANUFACTURING

The know-how and intellectual property will likely assist in anchoring the manufacturing technology domestically.

NATIONAL INTERESTS

The majority of key ingredients for pharmaceuticals are manufactured overseas. A major disruption in pharma imports would impose immense hardship on the U.S. population. The current domestic supply of life-preserving pharmaceuticals is estimated to last several weeks. A prolonged disruption lasting months to years, would cause extensive loss of life, as tens of thousands of U.S. citizens would lack access to drugs required to keep them alive.

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[6] https://novartis-mit.mit.edu/

[7] http://www.fiercepharmamanufacturing.com/story/vertex-jj-gsk-novartis-all-working-continuous-manufacturing-facilities/2015-02-09

TRANSLATIONAL R&D:

ENGINEERED CEMENTITIOUS COMPOSITES (ECC)

DESCRIPTION

There have been substantial advances in cement and concrete that will enable a next generation of civil infrastructure, buildings, and homes. Engineered Cementitious Composite (ECC) has 500x the ductility of current concrete, is self-healing to cracks, can be recycled, and is environmentally robust. The ductility of ECC allows the material to be manufactured in modules, and quickly assembled on site using simple fasteners instead of mortar, which increases precision, quality, speed, and environmental friendliness of onsite assembly. Additional research will further transform ECC into 'smart' concrete that can self-sense its state. ECC materials offer a proven advantage in seismically active areas since the material is tolerant to bending and tension loads. The challenge is that cost-competitive manufacturing methods and improved prefabrication methods are both needed.

Opportunity: The government has the opportunity to assist the development of ECC by providing targeted investment in key technology development areas and by supporting demonstration tests on bridges and other public infrastructure.

ECONOMIC IMPACT

There is a needed investment of $3.6T by 2020 to fix the U.S.'s infrastructure.[1] The U.S. manufactures $8B of cement per year, growing at a compound annual growth rate (CAGR) of 5.9%.[2] There is a global market for Concrete Admixtures that is $11.7B and projected to reach $18.1B by 2020, a 9.2% CAGR.[3] The U.S. holds approximately 1.9% of the global cement market.[4]

BROAD INDUSTRY IMPACT

ECC can be used virtually anywhere that standard concrete is used. This includes infrastructure projects, homes, buildings, and national defense applications. Because the material can self-heal and is ductile, the material stays intact over many years, eliminating the typical cost of periodic repair due to freeze-thaw cycles or cyclic loading. This decreases the cumulative life-cycle cost of the material, which can be substantial for long-life applications such as bridge decks (60+ years.)

IDENTIFIABLE MARKET FAILURES - JUSTIFICATION FOR FEDERAL INVESTMENT

While the underlying technology has been demonstrated in buildings as large as skyscrapers in Japan, U.S. companies and municipalities have been very slow to adopt it. The building industry is very conservative and slow to

[1] http://www.infrastructurereportcard.org/
[2] IBISWorld, 'Cement Manufacturing Market Research Report' Dec 2015
[3] Markets and Markets, 'Concrete Admixtures Market by Type (Superplasticizers, Normal Plasticizers, Accelerating Agents, Air-Entraining Agents, Retarding Agents, Waterproofing Agents, & Others), & by Application (Residential, Non-Residential, & Infrastructure) - Global Forecasts to 2020' Nov 2015 "The market size, in terms of value, of concrete admixtures is estimated to be USD 11.68 Billion in 2015 and is projected to reach USD 18.10 Billion by 2020, at a CAGR of 9.15% between 2015 and 2020."
[4] http://www.cembureau.be/sites/default/files/World%20Cement%20production_2.pdf

adapt new materials due to cost and liability concerns. Only materials that have been thoroughly vetted by in-situ testing become candidates for use in new structures or infrastructure.

INTERNATIONAL BENCHMARKING (US ADVANTAGES/ DISADVANTAGES)

The U.S. has demonstrated a resistance to using the technology, whereas Japan has been the first adopter to use ECC in buildings located in seismically active areas. Japanese companies have made considerable investment in testing ECC, and have used ECC as the core building material in several skyscrapers. Other countries are generally less risk adverse for novel construction technologies.

PRIVATE-SECTOR INVESTMENT

Investments in concrete companies by private capital is not very common. There is; however, opportunity for technology transfer to established cement and concrete manufacturers.

LEVERAGING STRENGTHS AND INVESTMENTS

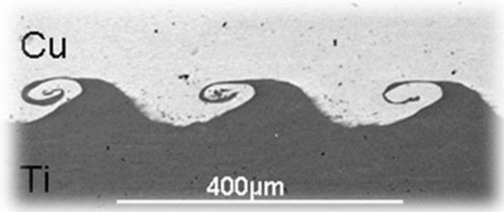
The U.S. invests in ECC research through the National Science Foundation, National Institute of Standards and Technology, and Michigan Department of Transportation.

US-BASED MANUFACTURING

The U.S. may be able to maintain a portion of the market, as import/export of cement in the U.S. is low relative to domestic consumption. Based on its experience with building in active seismic zones, a physical proximity to China, and a demonstrated willingness to invest in ECC, Japan provides a model for capturing a large share in ECC manufacturing.

NATIONAL INTERESTS

The U.S. is in need of a large civil infrastructure overhaul, and ECC presents an opportunity to provide a safer, lower lifetime cost solution. There are also national defense applications.



TRANSLATIONAL R&D: IMPULSE JOINING AND FORMING

DESCRIPTION

Impulse joining is an umbrella term for welding or mechanical joining methods that use forces and/or temperatures imparted over a very small time period. These include explosive welding, vaporizing foil actuator welding, and laser impact welding. Impulse forming, similarly, forms (or shapes) the material using forces imparted over a very small time period. This includes impulse presses, electromagnetic forming, explosive forming, and pneumatically driven forming machines.

Impulse joining offers a number of very important advantages, including higher joint efficiency (strength relative to the material being joined), the ability to join different materials to each other, and the ability to join otherwise un-weldable alloys. Impulse forming fundamentally changes the nature of the forming process using short duration impulses, which enables much lighter and more agile equipment. The method also enhances formability, improves conformal joining, and provides precise embossing, cutting, and shape control. Both process categories can be applied to high-value metals including aluminum alloys, titanium alloys, stainless steels, copper and selected magnesium wrought alloys. This opens up a host of new applications in demanding environments such as aerospace, defense and medical equipment.

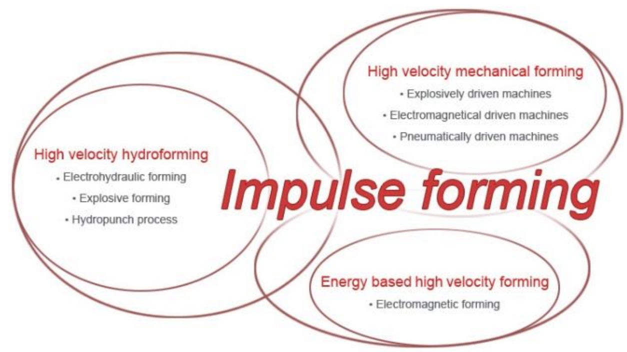


Figure 1: Impulse forming methods (graphic courtesy of i2fg.org).

The challenge is that the methods need to be further developed to work well with existing manufacturing infrastructure and have known process parameters.

OPPORTUNITY: The government has the opportunity to assist the development of impulse joining and forming by providing targeted investment in key technology development areas.

ECONOMIC IMPACT

The global welding market is expected to reach $25B by 2020, with a 4.5% compound annual growth rate (CAGR).[1] [2] About $5B of the market is in North America.[3] The adhesive manufacturing industry in the U.S. currently has $12B in revenue, growing at a 1.6% CAGR. [4] The metalworking machinery manufacturing industry is $34B in the U.S. [5] While impulse joining and forming are unlikely to capture the majority of these markets, the move towards light-weighting vehicles and the desired to form mixed material structures will drive adoption.

[1] Transparency Market Research, 'Welding Products Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2014 – 2020,' April 2015.
[2] bccResearch, 'Welding Equipment and Supplies: The Global Market,' Jan 2014.
[3] http://investor.itw.com/~/media/Files/I/ITW-IR/documents/presentations/welding-segment-overview-baird-conference-nov-2013-final.pdf
[4] IBISWorld, 'Adhesive Manufacturing in the US: Market Research Report,' Sept 2015.
[5] IBISWorld, 'Metalworking Machinery Manufacturing in the US: Market Research Report,' Dec 2015.

BROAD INDUSTRY IMPACT

Impulse joining and forming are applicable across many size scales, material types, and joint types, leading to a range of industries that will benefit from the technology, including automotive, aerospace, energy, and others.

IDENTIFIABLE MARKET FAILURES – JUSTIFICATION FOR FEDERAL INVESTMENT

While the underlying technology has been demonstrated to have high utility, the development of methods and tools that work with existing manufacturing infrastructure are needed.

INTERNATIONAL BENCHMARKING (US ADVANTAGES/ DISADVANTAGES)

Germany has a large presence in impulse forming, [6] and this may translate to a strong position in both impulse joining and forming. The U.S. has a presence in impulse joining research, as well as a presence in explosive welding, indicating the technology may have an advantage in the U.S. An international group devoted to impulse forming has been formed for research and advanced application development (i2fg.org), but the U.S. has very little representation.

PRIVATE-SECTOR INVESTMENT

While private capital investment in metal joining and forming technologies is not very common, there are large welding and metal forming companies that can invest to perform the final development stages.

LEVERAGING STRENGTHS AND INVESTMENTS

The U.S. invests in impulse forming and joining research through the National Science Foundation.

US-BASED MANUFACTURING

The U.S. has multiple industries that are likely to utilize the technology, including automotive, aerospace, energy, medical, and others. This will lead to the technology remaining anchored and integrated into those industries.

NATIONAL INTERESTS

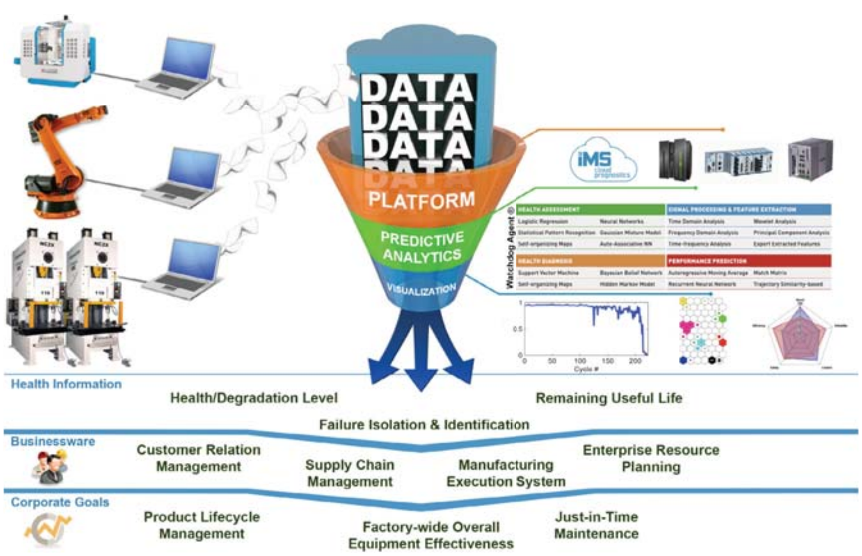
Many national defense applications will benefit from this technology.

[6] http://i2fg.org/

Predictive Analytics for Predictive Manufacturing System

Jay Lee
NSF IUCRC on Intelligent Maintenance Systems (IMS)
Univ. of Cincinnati

The emergence of big data, internet of things and cyber physical system drives the revolutionary shift toward predictive manufacturing. In the future manufacturing system, the machines are connected as a collaborative community. Predictive analytics exploits the patterns in historical data from the machine networks and quantifies the similarity among peers and among different patterns, thus to allow reliable prediction of machine degradation level, remaining useful life, machine operation risks and etc. The outcome of predictive analytics will guide decision making at shop floor level, business level and corporation level, and will eventually lead to faster product development, service innovations, and more efficient and reliable manufacturing system with predictive powers. The research of predictive manufacturing system consists of integrated platform, advanced predictive analytics and visualization tools.



Eight Criteria

1. **Economic Impact**: The predictive analytics of assets could save up 12% over scheduled repairs, reducing overall maintenance costs up to 30% and eliminate breakdowns up to 70%. The productivity can be boosted as much as 30%[1].

2. **Broad industry impact:** The predictive analytics has added "velocity" to everything we do in industry. It will impact the business process and systems such as e-procurement, supply chain management, customer relation management and enterprise resource planning. It accelerates product realization,

manufacturing, delivery and customer services. And it also improves the productivity, quality and cost[2].

3. **Identifiable Market Failures:** The LabView Watchdog Agent® Toolkit has been developed and packaged on different hardware and software platforms. National Instruments (NI) is supporting gloabbly. The tools are employed and validated using real-world data supplied by different company test-beds from various industries to achieve different diagnostics and prognostics tasks. The toolbox can be customized and reconfigured for virtually any application—from products and equipment, to complex systems or manufacturing lines. Standardized methodologies, platform independence and the reconfigurable nature of the Watchdog Agent® platform have enabled the development and deployment of next-generation maintenance solutions in many diverse applications.

4. **International benchmarking:** US is and will be one of the top two manufacturing economic in the future. Due to the 3rd industrial revolution, the current manufacturing systems have high amount of computer power and sensor and generate large amounts of data. The industry 4.0 will exploit substantial amount of data to improve the overall production and the design process. The only requirement for leveraging those data is advanced analytics and innovative thinking. Innovation is a key element of American culture, unequalled anywhere else in the world.

5. **Private sector investment:** In private sectors, companies like GE, Cisco and P&G are massive believers in connectivity and intelligent analytics driving improvements in productivity for manufacturing.

6. **Leveraging strengths and investments:** IMS has been a NSF I/UCRC member since 2000, it has been continuously funded by NSF for 16 years in the area of predictive analytics and industrial big data modeling for life cycle performance of industrial systems.

7. **US-based Manufacturing:**
   A reconfigured predictive platform is essential for diversified industries.

8. **National Interests:**
   The technology is aligned with either U.S. national security needs or energy independence goals, or enhancing health outcomes.

[1] P. Daugherty, *Driving Unconventional Growth through the Industrial Internet of Things*: Accenture, 2015.

[2] J. Lee, J. Ni, D. Djurdjanovic, H. Qiu, and H. Liao, "Intelligent prognostics tools and e-maintenance," *Computers in industry,* vol. 57, pp. 476-489, 2006.

TRANSLATIONAL R&D: RESEARCH DATA UTILIZATION

DESCRIPTION

The collection and analysis of large-scale research data will enable connections between problems and technological solutions, reduce or eliminate time and money consuming rework, accelerate discovery, and reduce time to market. This research data includes information created by universities, government, NGOs, and companies. With modern sensing and computing, the amount of data being created from science is rapidly expanding, and has become too big to effectively utilize. There is an opportunity for manufacturing to rapidly translate science data and discoveries to manufactured goods by improving the way we store, search, and access information—whether within or across organizations.

Opportunity: The government has the opportunity to assist the development and implementation of systems that better utilize research data by providing targeted investment in key technology development areas and implementing the systems into federally funded research.

ECONOMIC IMPACT

McKinsey & Company estimated in 2013 that open data could generate up to $3 trillion in value for the global economy across just seven industries, with $1.3 trillion benefitting the US.[1]

BROAD INDUSTRY IMPACT

While Big Data itself resides in the IT sector, the technology provides benefits to multiple industry sectors, and to organizations of all types and sizes. Improvements in data analytics, data-intensive computing, and machine learning have led to advances for speech and facial recognition, real-time speech-to-speech translation, and image interpretation and captioning systems, as well as prototypes for new devices like automated vehicles. Big Data has disruptive potential to make healthcare more personalized, enhance national security, expand applications of science and engineering, and better coordinate government services.[2]

IDENTIFIABLE MARKET FAILURES – JUSTIFICATION FOR FEDERAL INVESTMENT

While there have been some advancements in Big Data, the application to scientific discoveries translating to manufacturing has been minimal. Part of the challenge is that the technology cuts across so many industries that the benefit to any given company has not been enough to justify the full technology development costs.

INTERNATIONAL BENCHMARKING (US ADVANTAGES/DISADVANTAGES)

[1] McKinsey & Company, October 2013. Open data: Unlocking innovation and performance with liquid performance. http://www.mckinsey.com/business-functions/business-technology/our-insights/open-data-unlocking-innovation-and-performance-with-liquid-information

[2] President's Council of Advisors on Science and Technology (PCAST), August 2015. Report to the President and Congress Ensuring Leadership in Federally Funded Research and Development in Information Technology. https://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/nitrd_report_aug_2015.pdf

The U.S. has a substantial advantage in Big Data technology, with the majority of leading companies located domestically. Companies like IBM and HP come to mind, but a large number of other data-fusion and analytics companies reside in the U.S., including Palintir, Povotal, Splunk and Actian. This dominance can be augmented by advanced algorithms for analyzing big data generated by high technology workers in the U.S.

PRIVATE SECTOR INVESTMENT

Many Fortune 1000 firms are investing in Big Data. Nearly 27% of these companies are expected to have investments of $50 million or more in big data infrastructure by 2017 and more than 62% indicated having Big Data initiatives in 2015—nearly double the rate from 2013.[3]

LEVERAGING STRENGTHS AND INVESTMENTS

The U.S. government spends $140B on research and development,[4] with another $320B spent by industry.[5] This technology provides the ability to more efficiently use the R+D spending, as well as analyze the abundant data that results from it. Furthermore, U.S. National Labs have invested in generated some of the Big Data technology that will underlie research data utilization. [6] [7] U.S. universities have also developed much of the Big Data technology.

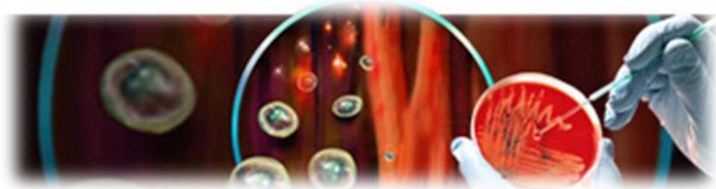
US-BASED MANUFACTURING

The U.S. is the global leader in science research, and has enormous resources and knowledge in IT and Big Data. Combined, these factors will allow the U.S. to have the largest and fastest benefit to this technology.

NATIONAL INTERESTS

Accessing data and technology is critical to national security and other sectors such as transportation; healthcare; education; electricity; consumer products; oil and gas; and consumer finance.[8]

[3] http://sloanreview.mit.edu/article/how-time-to-insight-is-driving-big-data-business-investment/
[4] http://www.aaas.org/page/historical-trends-federal-rd
[5] http://www.bloomberg.com/news/articles/2015-06-04/look-who-s-driving-r-d-now
[6] http://cda.ornl.gov/
[7] http://www.mcs.anl.gov/group/data-intensive-science
[8] McKInsey & Company, 2013.



TRANSLATIONAL R&D: REGENERATIVE MEDICINE

DESCRIPTION

Regenerative medicine is the process of creating living, functional tissues to repair or replace tissue or organ function lost due to age, disease, damage, or congenital defects. This field holds the promise of regenerating damaged tissues and organs in the body by stimulating previously irreparable organs to self-heal. Regenerative medicine also empowers scientists to manufacture tissues and organs in the laboratory and safely implant them when the body cannot heal itself. Importantly, regenerative medicine has the potential to solve the problem of the shortage of organs available through donation compared to the number of patients that require life-saving organ transplantation.

This interdisciplinary field has the potential to transform healthcare by translating fundamental science by fusing diverse technologies including biologics, chemical compounds, materials and devices. A very large U.S.-based medical device industry would see tremendous benefits by delivering new regenerative medicine solutions. Yet to meet the potential growth for this rapidly growing field, a coordinated effort is needed to address the many technical and regulatory blocks currently in place.

Figure 1: 3D printed ear scaffold (Wake Forest School of Medicine)

Opportunity: The government has the opportunity to assist the development of regenerative medicine by providing targeted investment in key technology development areas and providing smarter regulations.

ECONOMIC IMPACT

The global regenerative medicine market will reach $67.6 billion by 2020 from $16.4 billion in 2013, registering a compound annual growth rate (CAGR) of 23.2% during the forecast period (2014 - 2020). The small molecules and biologics segment holds prominent market share in the overall regenerative medicine technology market and is anticipated to grow at a CAGR of 18.9% during the forecast period. [1]

BROAD INDUSTRY IMPACT

Regenerative medicine represents an important new paradigm in human health with the potential to resolve unmet medical needs by addressing the underlying causes of disease. The applicability for Regenerative Medicine technology is very broad, including the ability to:

- Regulate the immune system (e.g., dendritic cells, allogenic universal T-cell, CAR-T, TIL, and TCR)
- Direct or control cellular differentiation (e.g., stem cell therapies utilizing MSCs and iPSCs, including genetic mapping)
- Engineer and grow functional 3D organ systems (e.g., tissue engineering, bioprinting, 3D printing, and biomaterials)

[1] Allied Market Research titled, "Global Regenerative Medicine Market (Technology, Applications, Geography) - Industry Analysis, Trends, Opportunities and Forecast, 2013-2020"

- Deliver therapeutic agents directly to cells (cell-based therapy, biomolecular cocktails, and liposomal drug delivery)

The ultimate goal is to develop manufacturing platforms that seamlessly allow for automation and standardization as the technologies above are scaled up to wide-scale deployment.

IDENTIFIABLE MARKET FAILURES - JUSTIFICATION FOR FEDERAL INVESTMENT

The pace of regulatory change is challenged to keep up with the speed that innovations are being developed in regenerative medicine. A critical requirement for a thriving U.S. industry will be the movement of early stage discoveries to viable products using an effective business model coupled with robust manufacturing capabilities that can meet the stringent regulatory environment.

INTERNATIONAL BENCHMARKING: (US ADVANTAGES/ DISADVANTAGES)

The strength of the existing U.S. medical device industry (closely aligned with regenerative medicine concepts) provides a meaningful competitive advantage to domestic regenerative medicine manufacturing. Specifically, the United States remains the largest medical device market in the world with a market size of around $136 billion. The U.S. market value represents about 45% of the global medical device market. The U.S. medical device market is projected to grow at a compound annual growth rate (or CAGR) of 6.1% between 2014 and 2017[2]. With more than 7,000 medical devices companies in the U.S., which are mostly small and medium enterprises (or SMEs), that employ around 400,000 people directly and more than 2 million people indirectly; however, the industry is highly fragmented.

In terms of disadvantages, the U.S. regulatory climate arguably is a major barrier. In translating technology from the research laboratory to the patient, technologies invented and developed in the U.S. frequently will leave the country for critical early stage clinical trials and approvals before coming back to the U.S. for later application to the FDA and entry into the U.S. market.

PRIVATE-SECTOR INVESTMENT

Med Tech Intelligence reports that $10.8 billion was raised in the regenerative medicine last year and that $806.8 million fell into the tissue engineering category, which hits the most relevant segment in which device manufacturers are involved (other categories: $6.8 billion for gene and gene-modified cell therapy and $7.0 billion for cell therapy). The top two sources of financing came from mergers and acquisitions, and corporate partnerships.

US-BASED MANUFACTURING

As noted above, the existing U.S. medical device industry offers a substantial advantage for the related regenerative medicine industry. There are more than 6,500 medical device companies in the U.S., mostly small and medium-sized enterprises

NATIONAL INTERESTS

National security is critically dependent on the readiness of our Armed Forces, including the timely return to duty of wounded warriors. Regenerative medicine is a rapidly emerging research area that targets the development of therapies that address acute and chronic injuries suffered by wounded warriors, which have resulted from training activities or from battlefield engagement

[2] http://www.espicom.com/worldwide-medical-devices-forecasts-to-2020.html

Translational R&D:

Cyber Security for Advanced Manufacturing

DESCRIPTION

The unauthorized access and control of cyber-controlled manufacturing systems is of particular concern in the manufacturing community. As software-based control and monitoring of manufacturing machines increases, the risk of malicious cyberattacks also grows. Manufacturing-specific cybersecurity research is in its infancy and has spawned from the broader, more mature cybersecurity domain.

Cyberattacks on manufacturing can take many forms. The famous Stuxnet worm was surreptitiously inserted into specific machine controllers at an Iranian uranium production site, first spying on centrifuge operation, and then disabling the systems without the operator's knowledge. Another devastating cyberattack is to introduce a flaw that compromises the manufactured product's design, rather than disabling the means of production. This indirect attack is particularly challenging since the effect is orders of magnitude beyond a single item failure. (Imagine, rather than a remote attack on a single vehicle, 1,000s of a brake system component were manufactured to fail prematurely). Moreover, most QA/QC protocols cannot adequately measure all aspects of a given physical component, particularly if the design changes are made internal to a component during the additive manufacturing process. While the manufactured product may look, feel, and measure like its original design, manufacturing flaws can be injected into the design such that only after many rounds of functional use is the attack realized.

Opportunity: The National Defense Industrial Association has recommended that government and industry collaborate on a) Developing the guidance for cybersecurity in manufacturing systems, b) identifying the relevant standards and best practices, and c) assisting supply chain partners with voluntary implement compatible solutions.[1] Commonality of expectations in business interfaces across DIB supply chains is highly desirable, and can be facilitated by adopting commercial concepts, standards and practices wherever possible

ECONOMIC IMPACT

The cybersecurity market is expected to reach $170B by 2020, with a compound annual growth rate (CAGR) of 9.8%. [2] The Federal cybersecurity sector of this market is expected to reach $22B by 2022, with a CAGR of 4.4%. [3] The larger economic implication is the prevention of massive disruption of manufacturing, and the economic impacts of cyber-physical attacks to manufactured goods.

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[1] CYBERSECURITY FOR ADVANCED MANUFACTURING, White Paper, National Defense Industrial Association, Manufacturing Division and Cyber Division, May 5, 2014

[2] Markets and Markets, "Cyber Security Market by Solution (IAM, Encryption, DLP, Risk and Compliance Management, IDS/IPS, UTM, Firewall, Antivirus/Antimalware, SIEM, Disaster Recovery, DDOS Mitigation, Web Filtering, and Security Services) - Global Forecast to 2020" June 2015

[3] Market Research Media, "U.S. Federal Cybersecurity Market Forecast 2017-2022," Feb 2016

Broad Industry Impact

A substantial portion of U.S. manufacturing is co-mingled with defense manufacturing, with flow down requirements for additional security already being added to DoD contracts. As manufacturing companies increasingly "go digital", enhanced security will become essential.

Identifiable Market Failures - Justification For Federal Investment

While individual companies are taking some steps towards cybersecurity, there is too much work and collaboration that needs to be performed for any single organization. Further, it is important to have the security measures adopted widely, not just by a few manufacturers.

International Benchmarking

Given the large manufacturing output of the U.S. and the adoption of advanced manufacturing, it is essential for the U.S. to protect these assets, independent of other countries cybersecurity progress. The U.S. also has a dominant presence in cybersecurity and a large defense sector, providing an advantage for production and consumption of cybersecurity technology.

Private Sector Investment

There venture capital investment climate for cybersecurity is very good, with $5.2B invested in the past 5 years, [4] and this is likely to continue for cybersecurity.

Leveraging Strengths and Investments

This security is critical for protecting U.S. infrastructure, U.S. defense, and a range of other areas of investment. This area also extends existing research in cybersecurity, leveraging universities and national labs. The US Department of Defense is particularly concerned about potential for cyber-attack based damage to manufacturing facilities and equipment at contractor facilities.

US-Based Manufacturing

The U.S. has a dominant presence in cybersecurity and a large defense sector, providing an advantage in maintaining a lead in cybersecurity.

National Interests

The Manufacturing Sector is considered to be one of the country's 16 Critical Infrastructure Sectors.[5] The Department of Homeland Security indicates that a direct attack on or disruption of certain elements of the manufacturing industry could disrupt essential functions at the national level and across multiple critical infrastructure sectors.

[4] https://www.cbinsights.com/blog/cybersecurity-industry-report/
[5] https://www.dhs.gov/critical-manufacturing-sector

TRANSLATIONAL R&D:

INLINE DETECTION OF MICROBIAL CONTAMINATION

DESCRIPTION

Contamination with potentially harmful organisms is a serious issue for manufacturers of a wide variety of pharmaceutical, food and beverage, and consumer products. Microbial testing today is difficult, expensive, and time consuming. Technology which could quickly test water systems, raw materials, agricultural products, and finished products inline would increase consumer safety, significantly reduce manufacturing and supply chain costs, reduce consumer prices, and reduce waste.

Opportunity: The government has the opportunity to assist the development of inline detection of microbial contamination by providing targeted investment in key technology development areas.

ECONOMIC IMPACT

The potential benefits of rapid, accurate microbial detection and measurement will impact a broad range of products (water, pharmaceuticals, foods and beverages, and personal care consumer products). Specific benefits include:

- Improved public health / consumer safety from eliminating outbreaks of water and food-borne illnesses,
- Quality assurance and cost reductions for a broad variety of industries
- Enhanced Homeland security from the ability to protect public water sources and waterways

BROAD INDUSTRY IMPACT

Pharmaceutical manufacturers, food and beverage manufacturers, health and personal care manufacturers, municipal water suppliers can all benefit from enhanced microbial detection. The conventional method for assessing microbial burden in water (membrane filtration) requires three to seven days to complete. Valuable opportunities for intervention could be missed due to a delay in obtaining test results. A more rapid (and accurate) assessment technology will be particularly interesting to the pharmaceutical industry in order to meet Good Manufacturing Practices (GMP) and ensuring product safety.

IDENTIFIABLE MARKET FAILURES - JUSTIFICATION FOR FEDERAL INVESTMENT

Significant cost and risk is associated with the R&D needed to turn inline microbial detection technology into a viable method for detecting the wide range of microbial strains. In addition, any resulting solution must also be integrated into the process validation step, follow manufacturing protocols (such as GMP) and meet strict quality control standards. This represents a very large barrier for a single company to overcome.

INTERNATIONAL BENCHMARKING (US ADVANTAGES/ DISADVANTAGES)

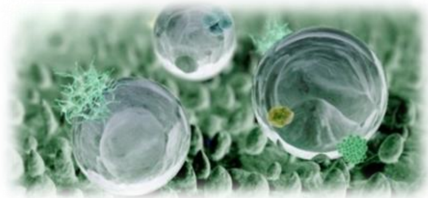
The technology has the potential to recapture the pharmaceutical manufacturing sector in the U.S. and maintain the know-how of the new processes domestically.

US-Based Manufacturing

R&D for microbial detection that is performed in the U.S. will benefit from domestic know-how of U.S. rules and regulations in industries such as pharmaceuticals. With U.S.-based R&D comes an increased likelihood that the systems would be produced here. For global deployment, microbial detection technology would be marketed by multi-national companies with operations in multiple countries.

National Interests

US public health would be enhanced by the ability to rapidly respond to bacterial outbreaks in water sources. As the need for clean drinking water becomes more evident, citizens will demand that local and state government be more proactive about assuring the cleanliness of water.



TRANSLATIONAL R&D: FUNCTIONAL NANO-COATINGS

DESCRIPTION

Nano-coatings are surface coatings on the nano-scale that provide a function not found in the material being coated. Examples of functions that have been developed or are in active development are superhydrophobic surfaces (for anti-rust, lower drag, electronics protections, etc.), reactive or catalytic surfaces, size based filters, photonics, adhesives, anti-bacterial surfaces, and nano-texturing. Simple nano-coatings that increase the durability of a surface or provide a level of hydrophobicity are already on the market. The first challenge is to enable functional nano-coatings possessing a wide range of advanced properties, such as the examples described above. The second challenge is that current manufacturing is slow and costly, yields low surface durability, and challenges persist with non-planar and complex geometries and uniformity issues.

Opportunity: The government has the opportunity to assist the development of functional nano-coatings manufacturing by providing targeted investment in key technology development areas.

ECONOMIC IMPACT

The market for nano-coatings is rapidly growing, with compound annual growth rate (CAGR) estimates for the next 3-6 years of around 25%, reaching approximately $16B by 2022.[1] [2] The United States currently holds roughly 40% of the nano-coatings market, with Europe and Asia splitting the remaining portion.

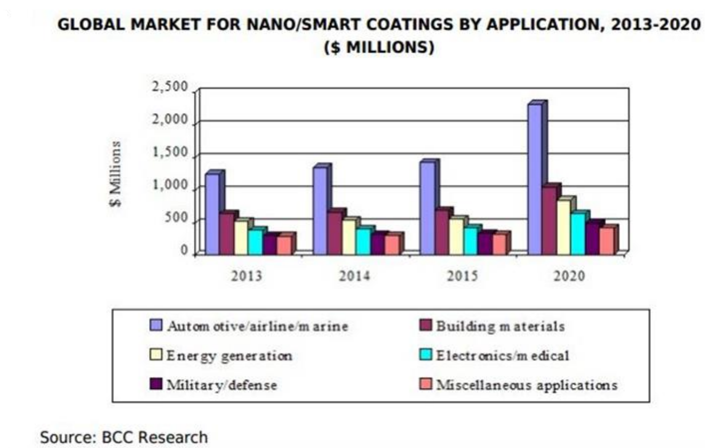


Figure 1: BCC Research, 'Global Markets and Advanced Technologies for Paints and Coatings,' July 2014

BROAD INDUSTRY IMPACT

Studies within the United States indicate that government economic incentives substantially increase the formation of firms focused on nanotechnology, with states that have economic innovation policies in nanotechnology seeing six times as many firms founded as those that don't have those policies.[3]

[1] Markets and Markets, 'Nanocoatings Market by Type,' Jan 2016.
[2] Transparency Market Research, 'Nanocoatings Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2013 – 2019,' Dec 2015.

IDENTIFIABLE MARKET FAILURES - JUSTIFICATION FOR FEDERAL INVESTMENT

A Government Accountability Office (GAO) report on nano-manufacturing found that there are, "Gaps in U.S. nano-commercialization funding or investment and related issues, which may hamper nano-innovation in the United States. … key gaps in government funding and private-sector investment for not only technology development but also manufacturing development…" [4]

INTERNATIONAL BENCHMARKING (US ADVANTAGES/ DISADVANTAGES)

The GAO indicated that inadequate U.S. leadership in international standard setting is a serious barrier to U.S. competitiveness in nano-manufacturing. In addition, aggressive actions and potential investments by competitor nations are hampering U.S. innovators' attempts to transition nanotechnology from R&D to full-scale manufacturing.

The GAO has stated that "…in key competitor countries, nano-commercialization funding or investment gaps (which present barriers to some U.S. innovators) do not apply or are being addressed." This indicates that without U.S. investment, the first mover advantage may be lost. There is a need for "…a stronger role for the United States in setting commercial standards for nano-manufactured goods (including defining basic terminology in order to sell products in global markets)."[5]

PRIVATE-SECTOR INVESTMENT

There are many examples of private sector co-investment in the technology, [6] [7] [8] [9] evidencing promise that there will be continued investment as the technology matures.

US-BASED MANUFACTURING

The GAO report indicates that "Lack of a national vision for a U.S. nanomanufacturing capability and limited technology transfer at U.S. universities… could make it more difficult to translate R&D investments in nanotechnology to commercial products—and thus could represent important limitations,"[10] and "Prior U.S. offshoring of manufacturing and, in some cases, current workforce limitations… can translate to competitive disadvantages when efforts are made to establish and maintain nanomanufacturing in the United States."[11] There are examples of U.S. nanocoating companies partnering with non-U.S. large firms to expand their manufacturing. [12]

NATIONAL INTERESTS

The GAO recommended that the U.S. develop a grand national strategy for a nanotechnology industry, since it could be a general purpose technology on the order of electricity or other public utilities.

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[3] Woolley, Jennifer L., and Renee M. Rottner. "Innovation policy and nanotechnology entrepreneurship." *Entrepreneurship theory and practice* 32.5 (2008): 791-811. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1248403

[4] Government Accountability Office, `Nanomanufacturing: Emergence and Implications for U.S. competitiveness, the Environment and Human Health,' Jan 2014 http://www.gao.gov/assets/670/660591.pdf

[5] GAO, 2014

[6] "Xtalic Raises $10 Million Funding to Commercialize Its Nanocoatings" http://www.nanowerk.com/news/newsid=8079.php

[7] "Rolith raises $5M for nanocoatings" http://vator.tv/news/2012-04-05-rolith-raises-5m-for-nanocoatings

[8] ConocoPhillips has invested in ModuMetal that makes Nano-layered coatings to improve material performance.

[9] "$5.2M Series A financing round in NBD Nanotechnologies, Inc." http://www.phoenix-vp.com/?p=104

[10] GAO, 2014.

[11] Ibid.

[12] "[Tesla NanoCoatings, Inc] today announced a strategic partnership with SK Global Chemical, a Korean company headquartered in Seoul." http://www.prnewswire.com/news-releases/tesla-nanocoatings-announces-investment-by-major-korean-chemical-co-strategic-partnership-will-result-in-rapid-us-global-growth-co-says-232501771.html

Translational R&D: Meta-materials

DESCRIPTION

Meta-materials are materials that have an engineered micro-structure to provide properties and performance not found in bulk materials. The types of meta-materials include mechanical, electromagnetic, acoustic, and others. Mechanical meta-materials can exhibit extraordinary strength/weight, stiffness/weight, damping, and energy absorption. Electromagnetic and acoustic meta-materials are constructed with subcomponents that are smaller than the wavelength of the type of radiation they are designed to manipulate. Note in Figure 1 that the resonator elements in the array are smaller than 1 um in width. Micro-scale features allow the manipulation of sound, light, radar, and other waves in highly unusual and beneficial ways. Other valuable meta-material characteristics include novel thermal moduli and active shape change.

The range of unique properties and others provide a huge range of applications for meta-materials in a number of areas such as structures, antenna, superlenses (lenses that can focus more than just light), cloaking devices, and absorbers.

A promising use for metamaterials is for high efficiency antennas. Use of metamaterials can effectively increase the antenna's effective radiated power far in excess of its physical size. This has profound implications for the miniaturization of microwave antennas, allowing smaller antenna elements to cover a broad frequency range while maintaining high gain.

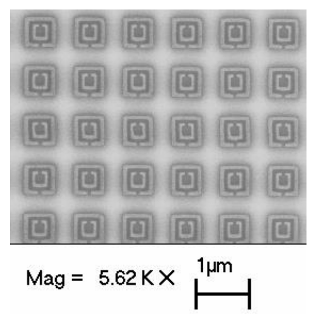
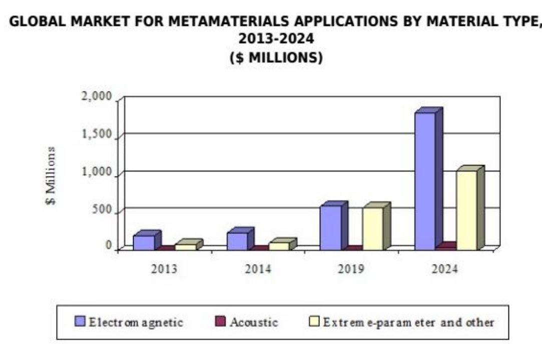


Figure 1: A magnified portion of a split-ring resonator array (from www.osti.gov)

The understanding of meta-materials has rapidly advanced, with modeling, simulation, design tools, and basic science providing the underlying technology to develop a wealth of designs with an array of interesting and useful properties. The technical appeal of meta-materials is unquestioned; the challenge is in creating a way of mass producing these advanced materials quickly and affordably.

ECONOMIC IMPACT

The market for meta-materials is rapidly growing, with compound annual growth rate (CAGR) estimates for the next 4-9 years of around 20-25%, reaching approximately $3B by 2024 [1] [2] [3]. The United States currently holds roughly 55% of the meta-materials market, with Europe coming in second.



Source: BCC Research

[1] BBC Research, `Metamaterials: Technologies and Global Markets,' May 2014.
[2] Transparency Market Research, `Metamaterials Technologies Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2014 – 2020,' Dec 2015.
[3] Brisk Insights, `Metamaterials Market Analysis ,' Feb, 2016.

BROAD INDUSTRY IMPACT

Mechanical meta-materials have applications in aerospace, defense, medical instrumentation, biomedical, optics, sensing, telecommunication, robotics, and other areas.

IDENTIFIABLE MARKET FAILURES - JUSTIFICATION FOR FEDERAL INVESTMENT

As an emerging technology, the development risk remains high for an individual company. Manufacturing technology that can manipulate materials on a microscopic scale does not yet exist, especially for mass manufacturing.

INTERNATIONAL BENCHMARKING (US ADVANTAGES OR DISADVANTAGES)

Transparency market research reports that, "The global metamaterials market was dominated by North America, from a geographical perspective. This region held more than 55.0% of the global metamaterials market in 2013. The region's firms are supported by government grants, high investment rates by venture capital firms in startups, and a large defense budget, which is one of the bigger application segments of metamaterials." [2]

PRIVATE SECTOR INVESTMENT

Venture Capital has invested $100M into metamaterials start-ups.[4] There are many examples of the private sector co-investing in the technology [5] [6] [7] [8], giving promise that there will be continued investment as the technology matures. There is a need for further private-public investment as Transparency Market Research reports, "…technical obstacles in the high-volume fabrication of metamaterials is expected to inhibit the growth of the global market." [2]

LEVERAGING STRENGTHS AND INVESTMENTS

The U.S. invests in meta-materials research through the National Science Foundation, the DoD, and National Labs.

US BASED MANUFACTURING

The quality of the workforce is a key factor for locating manufacturing in the U.S. The U.S. has the combination of high-skill and innovation for emerging technologies such as mechanical metamaterials.

NATIONAL INTERESTS

Many of the applications for mechanical metamaterials deal with ultra-high performance antennas and sensors. The Department of Defense has in interest in maintaining a lead in these areas over U.S. competitor nations.

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[4] Lux Research Inc., `Breaking the Rules: Emerging Metamaterials Drive Performance in New Directions,' Aug 2014.

[5] "Innovacorp announces 2M investment in MTI [Metamaterial Technologies Inc.]" http://www.metamaterial.com/innovacorp-announces-2m-investment-mti

[6] "Echodyne Corp announced in 2014 its intention to bring to market radar products based on metamaterials technology" http://echodyne.com/echodyne-announces-15-million-series-a-led-by-bill-gates-and-madrona-venture-group/

[7] "Evolv Technologies, Inc., which will commercialize new metamaterials-based imaging and detection technology … closed an $11.8 million funding round in late 2013

http://www.intellectualventures.com/news/press-releases/iv-spins-out-evolv-to-commercialize-metamaterials-security-imaging-technolo/

[8] Quantum Wave Fund investment in Nano-Meta Technologies, Inc. http://www.quantumwavefund.com/nanometatech.html

Translational R&D: Titanium

DESCRIPTION

Titanium is the fourth most abundant structural metal on earth, with titanium and titanium alloys in commercial use for the last 50 years. Titanium has many desirable traits, including a high strength/weight ratio, superior corrosion resistance and a high melting temperature. These traits are ideal for many applications, yet the use of titanium is limited to very selective circumstances due to high production costs. Decreasing the cost and complexity of titanium manufacturing will open up its use in routine (rather than exceptional) cases. Because titanium (unlike aluminum) is highly compatible with carbon fiber, applications in automotive, aerospace and other industries become practical – assuming cost-competitive production is assured. In the automotive market alone, vehicle lightweighting using hybrid titanium/carbon fiber construction has the potential to save quadrillions of BTUs of fuel energy in the US.

Recent advances in Titanium manufacturing have been developed that reduce the production cost of titanium feedstocks to 12% of current manufacturing costs for ingots, and down to 5% the cost for powder. Two manufacturing methods have been developed, one that directly creates titanium granules in a single step using a multi-arc fluidized bed reactor (MAFBR), and the other creates the titanium powder using an electrolysis process. Both processes create a titanium powder that can directly, or with minimal processing, be used to create products using sintering or 3D printing. These novel manufacturing methods contrast to the existing energy-intensive and costly titanium sponge to ingot process.

The challenge now is to develop companion manufacturing technology and knowledge to take advantage of lower production costs. Development is needed at the applied and translational stage to enable titanium to be produced quickly, affordably, and at scale. Additional development is needed to model the titanium parts made from the granules, as well as the mechanics of the granules behavior in various manufacturing processes. Non-destructive evaluation also needs to be progressed for titanium parts made from powder. The government has the opportunity to assist the development of titanium manufacturing by providing targeted investment and public-private partnerships in these key technology development areas.

BROAD INDUSTRY IMPACT

Titanium already spans many industries from aerospace to medical, with many more potential applications when cost barriers are diminished. Examples include low mass rotors for wind turbines, corrosion-resistant water turbines, high temperature turbocharger rotors, and high temperature supercritical CO_2 solar thermal turbines. It can also be used for ultra-high efficiency small modular reactors for onsite gas to liquid conversion. There is also demand for titanium in the emerging additive manufacturing market. Aerospace currently accounts for 40% of the titanium demand. The U.S. has about 50% of the titanium production processing supply chain. Approximately 325M pounds of titanium are produced per year. [1]

[1] http://c.ymcdn.com/sites/www.titanium.org/resource/resmgr/TiUSA2104Papers/BihlmanBillTiUSA2014WorldSup.pdf

Market Failures - Federal Opportunity

As an emerging technology, the development risk remains high for an individual company. The market is splintered into many companies, serving many different market needs; this reduces the returns for any given company's investment in the development of the manufacturing technology. The government has the opportunity to assist the development of titanium manufacturing by providing targeted investment and public-private partnerships in key technology development areas.

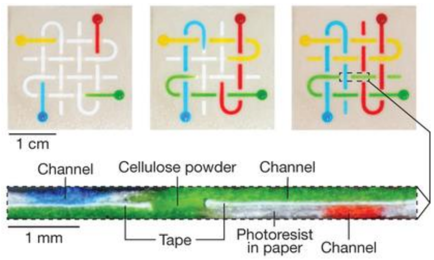
US Based Manufacturing

The U.S. has invested heavily in research in titanium though the National Science Foundation, Department of Energy, the US Military, and other entities. A strong domestic market though the defense industry and the automotive industry, combined with a skilled workforce are likely to keep a large portion of the manufacturing anchored in the U.S. With 50% of the titanium production capability already, and a lead on the manufacturing process, the U.S. is likely to have a first mover advantage. The high reliance on imported titanium sponge for processing may present a challenge to the U.S. holding the manufacturing advantage.

National Interests

There are a plethora of national security applications for titanium, including military aerospace, ground vehicles, and marine assets. Titanium is also a key component of renewable energy technologies from rotors to turbines. Vehicle lightweighting will have enormous fuel savings. Both of these areas advance the U.S. energy independence goals. Lower cost medical devices will assist progressing national health.

The Department of Defense (DOD) has particular interest in advanced manufacturing routes using low cost titanium. Of the $650 billion DOD budget, approximately 40% is used for maintenance. Therefore, the DOD has a substantial stake in developing mobile manufacturing units that can be deployed anywhere with the capability to manufacture replacement parts as needed. With the superior structural and corrosion resistant properties of titanium, it is the preferred lightweight metal. In fact, the DOD Metals Affordability Initiative has referred to aluminum as a legacy metal, and DOD focus is currently on titanium. Advanced additive manufacturing and powder metallurgy with titanium powder provide opportunities to realize mobile manufacturing envisioned by the DOD.



TRANSLATIONAL R&D: MASS-PRODUCED MICRO-FLUIDICS

DESCRIPTION

Microfluidics is the interdisciplinary development of micro-scale devices to manage fluid flow and processing. The lab-on-a-chip concept is a good example of microfluidics, where multiple processing steps are integrated into a single millimeter scale chip[1]. Microfluidic applications include biological research, medical diagnostics, advanced cooling, and drug delivery. There are also applications for detectors with national security applications.[2]

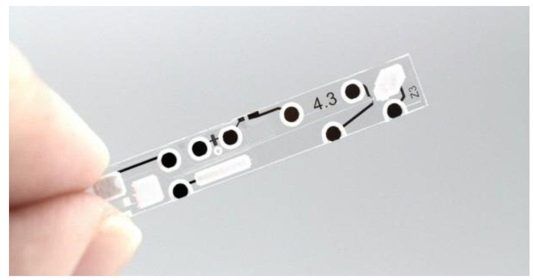


Figure 1: Microfluidic chip for fluid processing and diagnostics

While microfluidics is an established technology, there is still a great need for rapid and low cost methods to mass- produce the technology, especially designs that are complex and/or have biological components. While technologies such as electrokinetic pumping have been achieved in the lab[3], the scale-up challenges to broad production are significant.

The mass-production challenge is driven by the fact that their manufacturing method is "borrowed" from the semiconductor industry, resulting in high costs and slow production, especially for complex designs. Integrating biological components to these systems is another challenge resulting from the current manufacturing methods. A mass production method is needed that is built from the ground up for micro-fluidic devices. [4]

ECONOMIC IMPACT

The market for microfluidics is currently $3B, with CAGR estimates for the next 5 years of around 20-23%, reaching approximately $7B by 2020.[5] [6] [7] The United States is the largest market, with all of the major players based in the US. Overall, the market is highly fragmented, with new university startups entering the field and small microfluidics

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[1] http://www.micronit.com/blog/portfolio-item/lab-on-a-chip/?gclid=CNmo2YeZ0MsCFQoNaQodRPsK4g

[2] http://www.sandia.gov/microfluidics/

[3] ibid

[4] Mohammed, M. I., Haswell, S., & Gibson, I. (2015). Lab-on-a-chip or Chip-in-a-lab: Challenges of Commercialization Lost in Translation. *Procedia Technology*, *20*, 54-59.

[5] Markets and Markets, `Microfluidics Market by Material (Polymer, Glass, Silicon) Application (Pharmaceutical (Genomics, Proteomics, Capillary Electrophoresis) Diagnostic (POC, Clinical, Environmental, Industrial) Drug Delivery (Inhaler, Micropump)) - Global Forecast to 2020', June, 2015: "The Microfluidics market is expected to reach $7.5 Billion by 2020 from $3.1 Billion in 2015, at a CAGR of 19.3%" and "Major players in the global microfluidics market include Danaher Corporation (U.S.), Thermo Fisher Scientific, Inc. (U.S.), Agilent Technologies, Inc. (U.S.), Bio-Rad Laboratories, Inc. (U.S.), and PerkinElmer, Inc. (U.S.)."

[6] P&S Market Research, ` Global Industry Insight: Microfluidic Devices Market Development and Demand Forecast to 2020', July 2015: "Global Microfluidic Devices Market (Size of $1,886 million in 2014) to Witness a CAGR of 23% during 2015 - 2020"

[7] Transparency Market Research, `Global Microfluidic Devices Market (Size of $1,886 million in 2014) to Witness a CAGR of 23% during 2015 - 2020' May, 2014: "The global microfluidic device market was valued at USD 1,531.2 million in 2013. It is likely to grow at a CAGR of 22.8% during 2013 to 2019 to reach USD 5,246.4 million in 2019."

companies very active. Most companies are focused on specific market segments in their specialized areas such as diagnostics, proteomics and genomics, and drug delivery.

BROAD INDUSTRY IMPACT

The market of microfluidic devices is very broad, including life sciences, pharmaceuticals, and increasing point of care testing demand. Continuous innovations in microfluidic devices have led to transformation of drug discovery and development, gene expression analysis and genotyping in the pharmaceutical and biopharmaceutical industry.

IDENTIFIABLE MARKET FAILURES

While the microfluidics market is seeing strong growth (based on pharmaceutical and biotechnology research funding), the high prices for microfluidics-based genomic and proteomic analysis platforms and lack of proper healthcare/research infrastructure is holding back growth in emerging economies.

INTERNATIONAL BENCHMARKING (US ADVANTAGES/ DISADVANTAGES)

While North America and Europe are seeing healthy market growth (largely due to a highly developed healthcare system), the Asia-Pacific region is also fast-growing market owing to factors such as increasing geriatric population, rising incidences of lifestyle diseases, growing R&D expenditure, and rapidly growing healthcare industry.

INVESTMENT

In-vitro diagnostics (IVD) is a driving factor for investment. Companies such as Roche Diagnostics (Switzerland), Becton Dickinson and Company (U.S.), Abbott Laboratories (U.S.), and Cepheid (U.S.) find the technology appealing due to reduced reagent consumption and rapid turnaround of tests, all with high accuracy.

US-BASED MANUFACTURING

Most companies focused on microfluidics are based in the United States. [6]

NATIONAL INTERESTS

National security is critically dependent on the readiness of our Armed Forces, which includes keeping warfighters healthy by using health screening. Microfluidics can be used for battlefield testing of blood and other fluids to assure that soldiers remain in good health, even when deployed into remote locations.

TRANSLATIONAL R&D: ENERGY STORAGE

DESCRIPTION

Energy storage systems are designed to absorb/ and release electrical energy, providing a buffer between energy producers and energy consumers. Today's energy storage technologies are a critical part of new strategies to manage energy supply and demand, allowing utilities to implement innovative pricing strategies such as Time-of-Use Pricing.

When deployed, energy storage technology will enable utilities to improve performance to existing electrical grid without the expense of large-scale grid upgrades (see Table 1.) Energy storage can also decrease the amount of standby capacity equipment needed to meet surges and peak loads.

Uses for Electrical Energy Storage	
Demand shifting and peak reduction	Transmission and Distribution (T&D) Congestion Relief
Arbitrage (energy hedging)	Voltage Support
Frequency Regulation	Non-spinning reserves

Table 1: Uses for Energy Storage Technologies for existing electrical grid operators.

Five energy storage technologies lie firmly in the translational R&D stage, with proven technical viability but requiring additional R&D to be successfully deployed in the commercial space. These include 1) large-scale Lithium batteries, 2) Sodium-Sulphur batteries, 3) flow batteries, and 4) compressed air energy storage. A fifth technology (molten salt thermal storage) supports electrical generation from large-scale solar thermal facilities.

Opportunity: The government has the opportunity to assist the development and implementation of energy storage methods by providing targeted investment in key technology development areas and encouraging utility provider adoption.

ECONOMIC IMPACT

The McKinsey Global Institute (MGI) has identified energy storage as one of the world's top 12 disruptive technologies. The consultancy estimates the potential global economic impact of improved energy storage could be as much as $635 billion a year by 2025. The economic benefit of investments in energy storage is well documented for those technologies targeted to electrical grid improvements. For example, the cumulative benefit of adding short term energy storage to existing wind farms in the U.S. is in the range of $400-$700/kW over 10 years, with maximum market potential of nearly 20 GW over 10 years.

BROAD INDUSTRY IMPACT

Energy storage is a key enabling technology for utilities to manage energy consumption patterns. By coupling energy storage with innovative pricing schemes (such as peak pricing), utilities can avoid expensive upgrades and capacity requirements to meet periods of peak demand. Providers can smooth production by using energy storage for periods of low consumption and holding in reserve for peak demand. Peak-load shifting also has the potential to reduce transmission losses, further lowering costs.

Energy storage is also a vital component for a fully competitive wind or solar facility, eliminating the challenge of intermittent production (either diurnal or due to fluctuating weather conditions) and leveling the playing field for renewables to fully compete with fossil-fuel baseload generators.

Off-grid applications are a very viable market. Energy storage can buffer traditional power generator sets to off-set peak loads, or can provide continuous service for wind/solar intermittent systems.

IDENTIFIABLE MARKET FAILURES - JUSTIFICATION FOR FEDERAL INVESTMENT

The large, antiquated U.S. energy grid offers an enormous potential domestic market for U.S. producers to address, yet the highly regulated grid is a substantial barrier to entry for new technologies.

INTERNATIONAL BENCHMARKING (US ADVANTAGES/ DISADVANTAGES)

The U.S. utility market is highly regulated at the state level. This is a two-edged sword, acting as a barrier to foreign competitors but is also a substantial burden for U.S. firms, even if they are adept at navigating the byzantine U.S. electrical production system.

A large risk is that U.S. inaction will allow current R&D in Europe and China to box-out U.S. manufacturers without coordinated action between the U.S. government and private industry. For example, Germany's goal of sourcing 30% of its energy from renewables ("Energiewende") is stimulating innovative storage solutions and major investment in the transmission grid to balance out short-term fluctuations. Energy storage in China is strongly supported by the government with policy and loans, with storage capacity growing by nearly 60% in 2014 alone[1].

PRIVATE-SECTOR INVESTMENT

Duke Energy, a traditional utility (and one of the nation's largest coal consumers) has invested in "behind the meter" storage and energy management via an investment in the company Green Charge Networks.

Investments by large operators of wind and solar systems show that (for mature energy storage), the investment activity is strong. NextEra recently invested $100M in battery storage for its wind/solar facilities.

LEVERAGING STRENGTHS AND INVESTMENTS

The General Accounting Office has identified over $1.3B of federal support for battery and energy storage initiatives from 2009 to 2012. Funding agencies include: the Departments of Energy (DOE) and Defense (DOD), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the Environmental Protection Agency (EPA), and the National Institute of Standards and Technology (NIST).

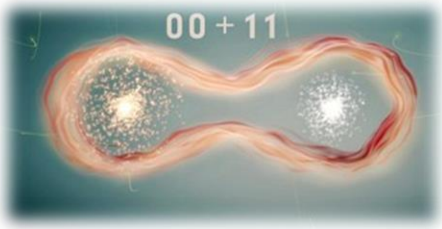
US-BASED MANUFACTURING

New companies to provide technology will be challenged to deliver cost-competitive, high technology equipment to U.S. based customers. U.S. based manufacturing can provide high tech, sophisticated storage systems and controls, which is an ideal match to high-tech industries seeking more diverse portfolio of products.

NATIONAL INTERESTS

A base of energy storage in the U.S. would work to decentralize power production, allowing for more localized production/storage/consumption of electricity. The result would be a more diverse and resilient power grid in the face of natural disasters or malicious attack (cyber or physical).

[1] Energy Storage China 2015 Held in Beijing, China Energy Storage Alliance (CNESA) report, June 30th 2015.



Translational R&D: Quantum Computing

DESCRIPTION

Quantum computing is reaching a technology readiness level that will begin to see the rapid transition from research devices to commercial products. Quantum computing applications include telecommunications, computation, sensors, and timing. In telecommunications, technology is focused on quantum key distribution and quantum encryption devices. Quantum communication techniques are especially valuable in creating highly secure data channels (for example, inter-bank transactions). At the quantum component level, development work includes multi-phase modulation units based on optical wavelength, photo detection, phase-shift detection and key generation. Quantum sensors use entanglement or superposition for high sensitivity magnetic measurements. Quantum timing involves chip-scale high-accuracy timekeeping electron transition frequency or other atomic scale properties as a frequency standard for timekeeping.

Recent advances have led scientists at MIT to claim that quantum computing is "much more an engineering effort, and not a basic physics question."[1] Scaling, however, remains an open challenge. Developing a manufacturing method that enables devices that sustain coherence (those that do not collapse the quantum states) is a substantial manufacturing challenge.

Opportunity: Quantum computing is positioned to be a very large market, and the U.S. government has the opportunity to provide targeted research development funding to progress the manufacture of quantum chips. This would enable U.S. based manufacturers to take the lead in manufacturing quantum technologies.

ECONOMIC IMPACT

The quantum computing market is expected to reach $5B by 2020. [2] This market can be seen as a subset of the High Performance Computing (HPC) market, which is expected to reach $37B by 2020, with a 5.45% Compound Annual Growth Rate (CAGR). [3]

BROAD INDUSTRY IMPACT

Quantum computing affects communication, computing, timing, and sensors, providing an impact in a wide range of industries.

[1] http://www.computing.co.uk/ctg/news/2449757/mit-scientists-build-worlds-first-scalable-quantum-computer ,04 March 2016

[2] Market Research Media, "Quantum Computing Market Forecast 2017-2022," Feb 2016.

[3] Markets and Markets, "High Performance Computing Market by Components Type (Servers, Storage, Networking Devices, & Software), Services, Deployment Type, Server Price Band, Vertical, & Region - Global Forecast to 2020," Feb 2016.

IDENTIFIABLE MARKET FAILURES – JUSTIFICATION FOR FEDERAL INVESTMENT

While individual companies are making progress towards realizable quantum computers (individual quantum chips, for example), the economic challenge to create such a complex solution is such that no one organization can address it alone.

INTERNATIONAL BENCHMARKING

Much of the intellectual property in quantum computing is owned by the U.S. and Japan (with the U.S. having a larger share). [4] The U.S. also has a large amount of quantum computing research activity and know-how. China has expressed a large interest and willingness to invest in quantum computers.

PRIVATE SECTOR INVESTMENT

There has been demonstrated private investment in quantum technologies, including a $50M investment by Intel, [5] a research focus by Google and Microsoft, [6] and venture funding for D-Wave (a quantum computer company). [7]

LEVERAGING STRENGTHS AND INVESTMENTS

The U.S. has invested heavily in the basic science that underlies quantum computing, from Universities to National Labs to the NSA.

US-BASED MANUFACTURING

U.S. expertise in quantum computing and an ecosystem of companies that will use quantum computing products increases the likelihood of quantum computing staying in the U.S.

NATIONAL INTERESTS

The impact for national security potentially large for quantum computing. It is imperative for U.S. security to be able to produce secure encryption and maintain a lead over other countries.

[4] UK Intellectual Property Office, "Eight Great Technologies Quantum Technologies A patent Overview," Aug 2014.

[5] https://newsroom.intel.com/news-releases/intel-invests-us50-million-to-advance-quantum-computing/ 03 September 2015

[6] http://research.microsoft.com/en-us/research-areas/quantum-computing.aspx

[7] http://blogs.wsj.com/venturecapital/2015/01/29/d-wave-systems-raises-c29-million-to-build-quantum-computing-software/ 29 January 2015